STRATEGY
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TEACHING A NEW DOG OLD TRICKS: REPLACING MAN WITH ARTIFICIAL INTELLIGENCE IN COMBAT AIRCRAFT

BY

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ABSTRACT

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By 2025 the US is counting on the Joint Strike Fighter (JSF) to be the backbone of its offensive aerial arm. JSF, with a service life of 40 to 50 years, is expected to replace the F-16 and A-10 in the USAF inventory. For the US Marine Corps, JSF will take the place of the AV-8 and F-18. The US Navy needs JSF for long range strike as a replacement for the F-14 and F-18. All told, the US intends to buy a stupendous number of JSFs—nearly 3,000 aircraft! Yet, increasing computer power affords the US the option of replacing manned strike aircraft with an uninhabited combat aerial vehicle (UCAV). Without a pilot, the UCAV offers tremendous increases in lethality and survivability. The enhanced effectiveness of modern air defense systems, coupled with the high cost of crewed aircraft and the increasing value placed on human life is forcing the adoption of unmanned aerial vehicles for the combat role. This paper takes the position *that at the current pace of technological advancement, the UCAV will provide the United States with a cornerstone combat capability far exceeding that of the JSF by 2016.* UCAV capacity will render JSF obsolete far ahead of its service life.

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PREFACE

There are several individuals who provided much counsel and inspiration for this paper, and it is fitting that I acknowledge them here. First and foremost I must thank my wife, Jody, my son, Peter, and my daughter, Julianna, for their great love and understanding without which I could not have finished this effort. Words cannot express my debt to them.

For the initial spark of the idea behind this article, I am indebted to Dr D. M. Bushnell of NASA's Langley Advanced Research Projects. His insights not only on the projected advances in computing power, but also for the fundamental impact it will have on our society lead one to visions of science fiction which may become science fact in less that the time-span of a generation.

I am indebted to Major Robin Vanderberry, USAF, of Air Combat Command's Joint Strike Fighter (JSF) office provided the latest information released publicly on both the JSF and the Unmanned Combat Aerial Vehicle (UCAV) Operating System. His relaxed recall on a plethora of matters conceals a razor mind and I am grateful for his insights and involved descriptions of the programmatics of the situation.

Dr David J. Musliner, Senior Principle Research Scientist at the Honeywell Technology Center, took time to answer my queries regarding his continuing work on a state-of-the-art Artificial Intelligence (AI) system known as SA-CIRCA (for Self-Adaptive Cooperative Intelligent Real-Time Control Architecture). His efforts at Honeywell, which fosters cooperation between a hard, real-time, mission-critical executive and a non-mission-critical artificial intelligence subsystem, may provide the perfect compliment with which to implement Dr Bushnell's world view.

Finally, I wish to express my appreciation to COL Ralph Ghent. COL Ghent was extremely helpful in guiding me along as my Strategy Research Project advisor. Always cordial, he kept me on track and I am thankful for having him as a sounding board and friend.

LIST OF ILLUSTRATIONS

TEACHING A NEW DOG OLD TRICKS: REPLACING MAN WITH ARTIFICIAL INTELLIGENCE IN COMBAT AIRCRAFT

"...every aspect of learning or any other feature of intelligence can in principle be so precisely stated that a machine can be made to simulate it."

John McCarthy,
Assistant Professor of Mathematics
Dartmouth College, 1956

Desperately evading the hostile air and ground defenses, the American lieutenant colonel fought her Joint Strike Fighter past the integrated air and ground defenses. Glancing at the rugged terrain slipping under her wings, she focused on the day's mission—a simple, but geo-strategically important, assignment: destroy the base camp from which insurgents were infiltrating the countryside of a US ally—a task akin to the 17 combat missions she experienced twenty-odd years ago as a lieutenant during Operation Allied Force. But things today had "gone south" rapidly. Threats in the target area had forced her flight to spend more time fighting for their lives than putting steel on target. The colonel felt positive that the camp had received some damage but knew it hadn't been destroyed. Coming off target, her wingman—bracketed by antiaircraft fire and surface-to-air missiles—didn't quite clear a jagged ridge. Frowning under her mask, she knew the "friendlies" would eventually win, but regretted the losses slowly mounting each passing day. It didn't have to be like this, she reflected. Allied Force, as well as Desert Storm before it, had proven the effectiveness of unmanned aerial vehicles in reconnaissance and surveillance. Adapting them to delivering lethal munitions was relatively simple. Everybody had seen it, but the point was dulled somewhere in the drawdowns, budgets, and forecasts of low-tech wars. The military application of unmanned aerial vehicles could have been so much more. The warble of her radar homing and warning gear broke her reverie as an unseen enemy fighter launched two missiles. Popping chaff, she performed a brutal 9 *g* turn catching sight of the missiles out of the corner of her eye. They were the last things she would ever see.

The USAF is currently considering replacing it's entire aging A-10 and F-16 fleets[1] on a one-for-one basis with 1,763 Joint Strike Fighters (JSFs) beginning in 2006.[2] Modern combat aircraft last much longer than their predecessors and General Michael J. Dugan, former Chief of Staff of the USAF, expects that trend to continue.[3] JSF is designed with a goal of being "flexible and relevant for the next 40 years of warfare."[4] That is quite impossible! Advancements in computer technology currently allow standard aerial weapons to be employed from an Unmanned Combat Aerial Vehicle (UCAV) which, without a pilot, offers tremendous increases in lethality and survivability. The enhanced effectiveness of modern air defense systems, coupled with the high cost of crewed aircraft and the increasing value placed on human life is forcing the adoption of unmanned aerial vehicles for the combat role. This paper takes the position that *at the current pace of technological advancement, the UCAV will provide the United States with a*

cornerstone combat capability far exceeding that of the JSF by 2016. UCAV capacity will render JSF obsolete at the beginning of its service life. In examining this issue one first needs to differentiate between a true UCAV and other unmanned platforms such as cruise missiles. With that understanding, we will examine the history of unmanned vehicle development, the technological innovations that make UCAVs possible today, the benefits available in non-manned rated designs, as well as understand concerns over possible UCAV limitations. After examining those issues we will outline the present developmental efforts and then explore possible futures.

DEFINITION

To perceive the latent value of the UCAV one must discern the distinctions between cruise missiles, UCAVs, and manned aircraft. A cruise missile is an unmanned powered aircraft that places the major high-cost components, propulsion and navigation, of the system in an airframe which, unfortunately, is destroyed with the employment of the warhead. UCAVs are similar to cruise missiles in that no human is aboard the aircraft. Yet, UCAVs have more in common with manned aircraft; the UCAV delivery platform dispatches only the warhead and short-range guidance system against the target, retaining the expensive delivery system for future use.[5] Most importantly, a true UCAV has no accommodation to house a human pilot. This eliminates from consideration as a UCAV those manned fighters converted to drones.[6]

The appellation, UCAV, which implies full autonomy, is presently a misnomer.[7] For the next ten to fifteen years the combat vehicle will remain under full control of a human operator—albeit one physically separated from the air vehicle. Man-in-the-loop allows for human rationale, judgment, and moral qualities. All UCAV designs follow one of two approaches: they are either "flown" by a human pilot or <u>largely</u> autonomous. Each of these approaches has far-reaching implications as regards the systems cost, sophistication level, operational effectiveness, as well as tradeoffs between these factors. Of late, American corporations have not indicated a particular bias towards any specific guidance/control philosophy.[8] Several sources consider the notion of a fully-autonomous robotic combat vehicle neither technologically feasible nor acceptable in operational, psychological, and arguably moral terms.[9] Each of these areas will be scrutinized later. Suffice it to say that as UAVs have demonstrated their capabilities in the areas of reconnaissance, surveillance, and communications they have gained a greater part of the inventory of most advanced air forces. We must expect the same for the UCAV and seriously consider it for the acquisition for a variety of roles presently undertaken by manned aircraft. While the nation experiences another Quadrennial Defense Review, strives to reduce the national deficit, and attempts to limit government spending, care needs to be taken to identify where UCAVs can best satisfy a requirement.[10] Surprising to many previously unconcerned with UCAVs, America revels in over 35 years of effort in these areas.[11]

US DEVELOPMENT HISTORY

The Vietnam War generated heavy losses of US strike aircraft and pilots attacking stiffly defended targets, causing both the US Navy and Air Force to examine alternative ways of getting weapons on target.[12] The U.S. pioneered a modification of the Teledyne Ryan Firebee, a Remotely Piloted Vehicle (RPV) aerial target drone that had previously been altered to a reconnaissance platform to gather intelligence over China and North Vietnam in the mid 60s.[13] By 1971 the USAF had the first workable UCAV in the BQM-34A Firebee; a drone capable of releasing a pair of MK-82 (500 lb. Class) bombs.[14] The next year saw the drones adapted to carry the AGM-34 Shrike anti-radiation missile.[15] By the mid-70s there were three variations of the Firebee: reconnaissance, electronic countermeasures, and strike. The strike version, designed to carry out the suppression of enemy air defenses (SEAD) mission, carried one AGM-65 Maverick missile in addition to a MK-82 bomb. Pilots, aboard DH-130H Hercules aircraft, capably controlled up to eight remotely piloted vehicles simultaneously.[16] However, with the end of the war further interest in the program flagged.[17]

WHY POSSIBLE NOW

Aircraft, and more importantly aircrew, losses have again spurred interest in the UCAV. Whether its the loss of an F-111 during the attack on Libya (Eldorado Canyon), two Navy A-6s in the Bekaa valley of Lebanon in 1983, or an F-117 over Yugoslavia in 1999, the threats have doggedly increased. Military losses, particularly in killed and captured aviators, have tremendously impacted the country's political mien.[18] The past several years have witnessed a rapid maturation of the technology necessary to make unmanned solutions workable. While there have been setbacks, past successes such as the 27 February, 1991 surrender of Iraqi troops to a Pioneer UAV give a glimmer of the future. The surrender of those troops is considered by former Vice Admiral Stanley R. Arthur, then commander of US naval forces during Operation Desert Storm, as "the first occasion in the history of warfare for human beings to capitulate to a robot."[19]

In the last decade, UAVs have proven themselves in a variety of combat support roles: surveillance, high resolution photography, meteorology and air sampling, target spotting, target acquisition and tracking, bomb damage assessment, and electronic intelligence gathering in the military forces of a number of countries.[20] As a testament to their efficacy, there are over 40 unmanned aerial vehicle designs presently on the world market.[21] Concerns abated by their reliability, current unmanned strike systems such as the UGM-109 Tomahawk Land Attack Missile (TLAM) and the AGM-86C Conventional Air Launched Cruise Missiles (CALCM) have earned themselves a preferred place in the contemporary national arsenal.[22] Technology is now advancing at such a pace as to allow UAVs to function in other airpower roles such as electronic combat, strike and air defense in either a totally autonomous mode or as

remotely directed from either airborne or surface stations.[23] The UCAV revolution is just getting under way.[24]

As with all types of Unmanned Aerial Vehicles, the main impediment has been the unwillingness of the manned aircraft lobby to relinquish this role; though there are signs that the atmosphere is now more amenable.[25] In 1996 the chairman of the Air Force Scientific Advisory Board, Dr Gene H. McCall, anticipated the emergence of the UCAV.[26] General Ronald R. Fogelman, then USAF Chief of Staff, agreed. Fogelman believes that after reconnaissance, "the next area that starts to make sense for UAVs is some source of unmanned attack airplane."[27] One senior service official commented that, by 2050, he envisioned there would be no manned aircraft in the US military inventory. However, for the short term UCAVs are seen as a companion to, rather than a replacement for, manned aircraft.[28] Other countries with advanced airpower are showing interest in UCAVs. The Australian Minister of Defense, Ian McLachlan, referring to the issue of the replacement of the F/A-18A/B Hornet between 2010 and 2015, asserted: "I cannot say what will replace the Hornet at this stage. I do not even want to prejudge whether it will be a piloted aircraft—remember what I said earlier about challenging pet prejudices."[29]

It appears as if the institutional mindset of several Air Forces may accept removing the man from the machine. But is it technically feasible to remove the human on a combat aircraft? Lt Col Michael B. Leahy, USAF deputy program manager on UCAV for the Defense Advanced Research Projects Agency (DARPA), believes "there are no technological miracles needed" to make a UCAV work. Rather he says, success will hinge on whether someone can integrate these technologies into a reliable platform. Leahy, located at the Aeronautical Systems Center, Wright-Patterson AFB, OH, believes that technological developments in propulsion, composite materials, multi-spectral stealth, guidance systems, and the miniaturization of sensor and weapon systems now allow relatively cheap UCAVs to operate.[30] Cost is a definite factor, and one examined in more depth later. It is enough to note here that advances in computer technology, communications, flight controls, and global positioning have greatly shrunk the size and cost of navigation equipment.[31] Eric D. Knutson, Lockheed Martin's UCAV program manager explains that solutions for the critical issues—involving the human system interface—are directly available from the commercial market.[32]

Industry presently provides an extensive range of instruments available for UAVs. To carry more diverse sensor packages UAV designs are getting larger and are employing more powerful engines. Yet, due to the increasing miniaturization of components, instrument packages are getting smaller and lighter. Therefore the prevailing increase in size and power is not inevitable.[33] Another project sponsored by DARPA, microelectrical mechanical systems (MEMS), allow entire laboratories to be miniaturized so that they fit on the head of a pin.[34] The Lockheed Martin owned Sanders company, is developing MicroSTAR, a six inch long UAV which weighs about 3 ounces. Despite its diminutive size, MicroSTAR will carry an

autopilot, inertial navigation system, global positioning system, day and night TV, and datalink.[35] Extremely small, the aircraft are difficult to control—humans are just not able to react in real time.[36] MicroSTAR is by no means alone. Scientists at the Institute for Microtechnology in Mainz, Germany have built a 2 centimeter long helicopter powered by two electric motors. Others at the Massachusetts Institute of Technology are looking into the viability of insect size, jet-powered UAVs.[37] Technological advances such as these make the UCAV proposed by Boeing to appear outmoded, cumbersome and in-elegant. Yet, the UCAV will deliver relatively cheap munitions on the battlefield for the first half of the century and offer: increased airframe capabilities leading to increased lethality and survivability, decreased risk of losing public support due to killed or captured airman, and substantial cost savings compared with operating manned aircraft. All of these are benefits derived from eliminating the pilot from the machine.

UCAV BENEFITS

Increased Airframe Capabilities Leading to Increased Lethality and Survivability

During the 1980s, NASA and Rockwell International collaborated on the construction of a highly maneuverable advanced technology (HiMAT) aircraft. Remotely piloted, HiMAT gave some impressive demonstrations. Its small size and absence of a vulnerable human body on board made possible aerobatics which no manned aircraft can match.[38] Likewise, a UCAV can be designed to perform maneuvers which would cause a human pilot to lose consciousness.[39] Merely adapting a conventional fighter would not produce the operational capabilities—nor the cost savings.[40] Although such a craft could be flown in manned or unmanned modes it would have only minor increases in capabilities (F-102 target drones at Holloman Air Force Base can pull 12*g*s while the pilot in a modern fighter is limited to a maximum of 10*g* because of the effects of *g*-induced loss of consciousness).[41] Eliminating manned-rated requirements, aeronautical engineers profess that 15 to 20*g* are possible with available materials.[42] Furthermore, they note that 20*g* could give an airframe the capability not only to out turn manned hostile fighters but even the enemy's missile armament.[43]

Maneuvering is only part of the battle, masking an aircraft's signature is critical. In the past, eliminating the pilot would not necessarily have had as drastic an effect on the construction of the platform. For instance, a radar antenna required the same size to get the same performance, so shrinking the airframe was not practical. Today, with conformal arrays and other aids in compacting sensors, the aircraft size can be dramatically reduced. Additionally, to reduce weight and size further it may soon be militarily sound to replace on-board sensors with links to off-board sensors (an idea considered and then discarded for the JSF).[44] Human aviators limit mission duration, require oxygen pressurization, and need over the nose visibility (which dictates location of propulsion systems). Manned aircraft have limited options for shape and cross section area and thereby provide sub-optimal forms for minimizing drag and

radar cross section.[45] Eliminating the pilot allows options for signature suppression. UAV designs become "stealthy" by simple changes such as positioning engines on top of the fuselage. Thermal suppression and diffusion systems as well as radar absorbing materials could also be used.[46] The fuselage could be shortened and shaped for optimum drag and efficiency. Removing the cockpit "bulge" renders a large vertical rudder unnecessary. Vertical tail surfaces would disappear—replaced with thrust-vector controls.[47]

Beyond the stealth attributes, another benefit of an unmanned aircraft is that it could loiter in an area for extended periods—long beyond the duration of a human pilot.[48] Additionally, UCAVs can fly at extremely high altitude. All manned aircraft, except a few special mission platforms, are limited to altitudes below 50,000 due to pressure constraints on the aircrew. Unhampered by that restriction, UCAVs could deliver precision guided munitions from exceptional heights.[49] At the other end of the altitude spectrum, a UCAV delivering unguided iron bombs could release weapons much closer to the intended impact point, and therefore more accurately, due to the capability to pull 20*g* off target.

An old adage asserts: Any target worth attacking is worth defending. Aircraft today face defenses increasingly designed to cope with stealth. The result is stealthy aircraft each so expensive that it can only be risked on the most important missions, and—because of their price tag—there are few of them. Other aircraft must be prepared to carry out less critical missions, yet may still have to face advanced air defenses. At the same time, significant casualties among the aircrew will remain undesirable if not politically unacceptable.[50] Saddled with budgetary constraints and manpower limitations, many observers feel that the time to begin aggressively pursuing UCAVs has arrived.[51] "Robot" airplanes designed and built for jobs too boring, hazardous, or expensive for aircrews to fly are the perfect choice.[52]

The Defense Department is investigating UAV designs that can laser-designate targets, conduct SEAD, and attack heavily fortified, high-value targets with enough speed and stealth to survive and fight again another day.[53] The absence of a pilot adds enormous flexibility to regional commanders who would be less hesitant about risking assets until air defenses are eliminated.[54] UCAVs can be sent on what would otherwise be "suicidal" missions--pilot casualties would cease to be a factor.[55] A 1993 Lockheed Martin study concluded that future U.S. administrations would look unfavorably on using manned assets to achieve military objectives.[56]

Decreased Risk Of Losing Public Support Due To Killed Or Captured Airman

Eric D. Knutson, Lockheed Martin's UCAV program manager stated that the public "will no longer stand for having military personnel wounded." He continues "Altogether this has led to the conclusion that we can't defend ourselves in the same way we use to. We can't afford it and the people don't want to do it."[57] Dr Armand J. Chaput, head of Lockheed Martin's integrated UCAV product team, echoes Knutson. Chaput says the US has a "national aversion to crew loss or capture."[58] Others point to the National

Command Authorities and senior military leaders as unwilling to accept casualties while protecting national interests. Manpower, they say, is considered so dear, with the services now smaller, that casualties take on additional sensitivity.[59]

No matter the source, operations in support of United Nations and NATO have borne out the need to overfly hostile territory without the risk of losing a pilot, both in the Gulf War and later in Bosnia.[60] Even the badly mauled and confused Iraqi air defense system downed Tornados in 1991.[61] Manned operations necessitate elaborate and daring operations to rescue those who are shot down—demonstrated by the quick recovery of the F-117A pilot over Yugoslavia. From the downing of Francis Gary Powers over the Soviet Union in 1960 to the extraordinary effort to recover Captain Scott O'Grady in Bosnia 1995, senior leaders have learned through painful experience the debilitating effect captured pilots can have on both diplomacy and military operations.[62] UCAVs with their stealth, speed, and agility attack targets with impunity. Should one be lost, the misfortunate circumstance of a killed or captured airman is lacking.

Substantial Cost Savings Compared With Operating Manned Aircraft

While downed airman are politically expensive, training one is measured in years and millions of dollars.[63] Retaining pilots in peacetime has become a major challenge. USAF Pilot retention is down 41 percent and expected to decline. The number of fliers taking Aviator Continuation Pay has dropped 50 percent while approved separations are up 240 percent. These are disappointing results given that the Air Force has increased flight training rates, raised the active service commitment for pilot training to 10 years, extended continuation for twice-deferred Majors to 24 years, and invited former pilots to apply for voluntary recall. These efforts left the USAF 648 pilots short of its 13,986 requirements in 1998. By 2002 the shortage is expected to grow to almost 2000.[64] Favorably, UCAVs may not need pilots in the traditional form. UAVs are currently operated by pilots but according to Rich Alldredge, Boeing's UCAV program manager at the Phantom Works, it has not yet been determined if pilots would be the ultimate or best choice as operators in the future. This definitely requires a cultural change.[65] Even the training of a UCAV pilot would be alien to those of manned aircraft. UCAV "pilot" training would be moved into simulators, eliminating the majority of training and proficiency costs in fuel, maintenance and accidents.[66] The second and third order effects include a diminished base support structure (flight surgeons, life support technicians, flight records clerks) are staggering. Operational support missions including search and rescue may be reduced or eliminated.[67]

The pilot and supporting subsystems make up 15 percent of the aircraft payload weight and 50 percent of the cost of a modern fighter. Without a cockpit, engineers could reduce aircraft size as much as 40 percent and attain equal performance in range and weapons payloads.[68] Through these efforts and with large production runs, commonality of service variants, and modular design, Larry D. Birckelbaw, of DARPA's Tactical Technology Office, expects the UCAV to come in at "one-third the cost of a JSF," or

around $11 million in 1999 dollars.[69] USAF Colonel Michael Francis of DARPA's Advanced Systems Technology Office believes a UCAV can be built for even less: $3 to 5 million per aircraft.[70] An amazing prediction when one considers that each TLAM costs $1.4 million and the airframe is destroyed every time one is used.[71]

While the fly away cost of a UCAV is attractive, the Department of Defense (DOD) is concerned about the ability to fund both current operational and modernization efforts. Some studies suggest that buying the force structure and investment program found in the Pentagon's 1997 Quadrennial Defense Review may require nearly doubling the current procurement accounts. Projects such as the F-22, F/A-18E/F, and JSF represent $350 billion in future investments (nearly 40 percent of the cost of the Pentagon's top 20 programs). Another budgetary concern centers on controlling Operations and Maintenance (O&M) accounts. O&M, as a percentage of the defense budget, is at an all time high. Until 1965, it accounted for 25 percent of the defense budget. By 1990 it had risen to 30 percent. O&M currently accounts for 37 percent of defense expenditures while the projection for 2005 is $100 billion per year (10 percent above last year's figure).[72] The UCAV provides a way to dramatically curb these costs.

Unlike manned aircraft that must be flown frequently for the pilot to maintain proficiency, the UCAV would be flown only occasionally, and otherwise remain in storage, with the majority of its operator training conducted on simulators.[73] Studies indicate that operations and support costs of a UCAV will run 75 percent less than that of an F-16 squadron.[74] By comparison, JSF overall potential life-cycle cost savings are anticipated at 33-55 percent of those of a nominal F-16 unit.[75] Other long standing conventions will be turned upside down as well.[76] Today the Air Force maintains a pilot-to-fighter aircraft ratio of 1.3-to-1. In UCAVs, the ratio will be reversed: one operator will control many UCAVs at once. Lockheed's Dr Chaput has simulated up to six UCAVs operated simultaneously by a single person and found it to be "very manageable."[77]

CONCERNS OVER UCAV LIMITATIONS

While there are many advantages to removing the pilot from a combat aircraft there are significant concerns and limitations. UAVs have been used for a variety of roles since before the Second World War. Since then, enormous sums of money has been expended on projects—despite repeated claims that the technology is on the verge of a break-through—which have yet to fulfill their promise. Progress has been painfully slow, with some spectacular failures along the way—for example the Lockheed Aquila for the US Army and the GEC-Marconi Phoenix for the British Army.[78] These examples emphasize the contrast between the (expected) simplicity and low-cost of the air vehicle and the extreme sophistication and complexity of the overall operational system, which includes not only the UCAV itself but also the ground station, control links, and logistic support.[79] Concern over UCAVs ability to meet mission requirements is

primarily centered on limitations involved with communications, and—to a lesser extent—anxiety over limited flexibility, flight safety, and the moral issues of removing the pilot.

Communications

Maj Gen Kenneth Israel, Director of US Defense Airborne Reconnaissance Office (DARO), stressed communications as the overriding problem in his FY97 report.[80] Deconfliction of radio frequencies during simultaneous operations is a top priority he explains.[81] Indeed, swamping the communications pipeline is Air Combat Command's top concern. Full and effective combat use of a UCAV strictly depends on uninterrupted availability of adequate worldwide command control.[82] Satellites can be attacked by anti-satellite missiles, jeopardizing the ability to control a UCAV.[83] Even a temporary or partial interruption in the direct links between human operator and sensors is likely to result in loss of situational awareness making it difficult to complete a mission efficiently if at all. This will not, however, result in the loss of the platform as plans call for an autonomous autopilot capable of loitering or making a return to base decision.[84]

Others fear that man-made electrical, magnetic, or other forms of interference could result in entire groups of UCAVs shot down.[85] They see possibilities for high power microwaves and lasers that may, for example, penetrate an aircraft cockpit—shutting down digital engine controls, changing mission commands, or making other surreptitious inputs like penetrating flight controls and forcing an uncommanded break turn.[86] Communications failures and reliance on links for situational awareness are not problems restricted to UCAV use alone. Manned systems are relying more heavily on off-board sensor use and data relays.

Limited flexibility

Even with unbroken communications links, skeptics perceive UCAV use as restricted to carefully planned missions, attacking only pre-selected and well-identified targets. They feel that the development of search and destroy missions against targets of opportunity seem to be outside what is technologically feasible of a UCAV.[87] This runs counter to combat proven UAV experience. Reconnaissance and surveillance UAVs such as Pointer, Pioneer, and Predator have proven themselves, in the Gulf War and Kosovo, extremely versatile in handling real time mission changes on the tactical battlefield.[88]

Flight Safety

Few doubt Predator's mission effectiveness. Yet critics point to the frequent mishaps current UAV systems experience during take-off and landing—far more than manned aircraft. Additionally, they note that UAV flight operations are difficult to integrate with manned aircraft requiring exhaustive separation procedures. Employing UCAVs, it is postulated, will unavoidably exacerbate flight safety issues, increase risk for in-flight collisions between manned and unmanned aircraft, and require rigidly separate time slots and/or geographic areas.[89] However, the Air Force concept of operation mandates operating UCAVs

alongside manned aircraft. Artificial Intelligence has come a long way and the DARPA/USAF System Capability Document (SCD) requires the UCAV to be able to "respond to ATC [Air Traffic Control] instructions for terminal coordination and safety."[90]

Moral issues of removing the pilot

The last argument against UCAVs is philosophical rather than technical in nature. Concern expressed by Frank Capuccio, Lockheed Martin's JSF program manager, puts it simply "What the Air Force has to come to grips with is, who is really going to commit to release...a missile or drop a JDAM" without a human being in the cockpit to "look the target over?"[91] DARPA's Birckelbaw doesn't see that as a problem. At this point, he doesn't see a machine deciding to launch weapons on its own. He feels there will have to be a human involved to authorize the use of lethal force.[92] Critics of this viewpoint point to TLAM and CALCM, where a weapon is given a target and launched—striking the target several hours later without any human involved in reviewing the target. Amplifying the problem, these cruise missiles cannot be recalled or aborted once launched. UCAVs, however, will be able to retarget or withhold weapons right up until the point of release.[93]

PRESENT

These limitations do not alarm Maj Gen Israel. As Director of DARO, Israel declares "UAVs are going to be a big, high leverage, payoff capability for us." And UCAVs will be leading the way. Currently, UAVs are roughly 30 percent of DARO's overall budget, which also funds operations of the U-2 and RC-135 Rivet Joint aircraft. Gen Israel anticipates the next few years will bring significant changes with as much as 75 percent of the budget going to UAVs and their sophisticated ground stations and sensors. This view is not held by some on the Senate Appropriations Committee which, in the Fiscal 1998 defense spending bill, asserted that the Pentagon had put too much emphasis on UAVs, at the expense of manned systems. The Senate, discouraged by the slow progress of UAV developments, believes that almost 20 years' needed upgrades to manned, proven systems have been consistently sacrificed for yet-to-be realized UAV potential.[94]

DARPA/USAF Initiatives

DARPA and the USAF disagreed. In April 1998, DARPA awarded 10 month contracts worth $4 million each, to four companies for the preliminary design of a UCAV advanced technology demonstrator (ATD).[95] Phase I was completed in February of 1999. Phase II began in March 1999 with the selection of Boeing Phantom Works to continue development and produce two vehicles. Government funding of $110 million covers the 42 month effort while Boeing is investing $21 million. The first aircraft, Figure 1 below, is projected to fly in early 2001. Demonstrations of increasing difficulty including autonomous ground operations, inter-vehicle communications, multi-vehicle flight operations, operations with manned aircraft

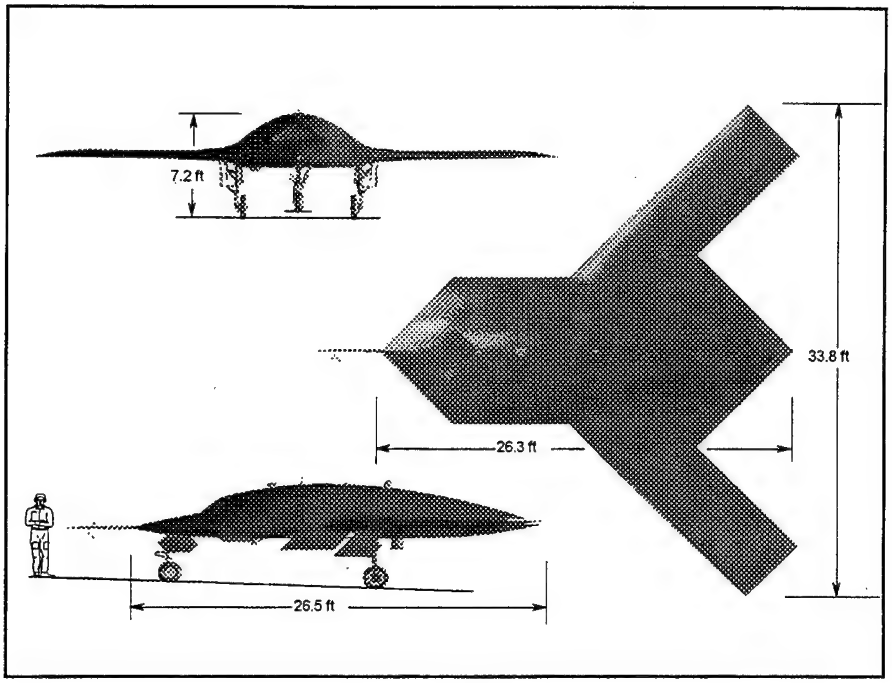

FIGURE 1

Boeing's design sports a wing span of 34 ft—similar to the F-16 or F-117, shown in Figure 2 below. Powered by an AlliedSignal F124 turbofan engine centerline in fuselage, the UCAV will weigh 8,000 lbs. empty with a gross weight of 15,000 pounds. For ease in storage and transportation, the UCAV will have removable "dry" wings (which attach in 1 hour) and all-electric flight controls. Carriage of all current munitions as well as those anticipated will be in two internal weapons bays. Operational aircraft would have hardpoints for external fuel tanks or weapons. An inflight refueling system might also make it to production. Each UCAV will be stored in an individual container. Deployments to forward locations can be made in storage containers of which six fit in a C-17 or twelve on a C-5.

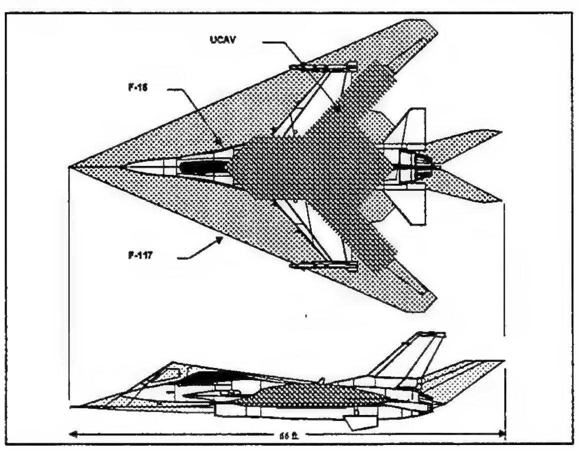

FIGURE 2

All attributes of Boeing's UCAV, including aircraft performance and autonomous flight operations to conduct SEAD missions are to be demonstrated. To accomplish this a UCAV must have a level of on-

All attributes of Boeing's UCAV, including aircraft performance and autonomous flight operations to conduct SEAD missions are to be demonstrated. To accomplish this a UCAV must have a level of on-board intelligence that would permit the UCAV's computer system to react to changes in the tactical picture and to certain low-level threats.[97] Through the efforts of Dr David Musliner, Senior Principle Research Scientist at the Honeywell Technology Center, a state-of-the-art Artificial Intelligence (AI) system is under development. The program known as SA-CIRCA (for Self-Adaptive Cooperative Intelligent Real-Time Control Architecture) fosters cooperation between a hard, real-time, mission-critical executive and a non-mission-critical artificial intelligence subsystem.[98] This meshes with the USAF's desires for selectable levels of autonomy to accommodate different missions and rules of engagement.[99] Additionally, target acquisition capability should include search, detect, track, identify, and prioritization of multiple targets at tactically significant ranges to cue and employ weapons in adverse weather, both day and night.

The propulsion system must not only be low maintenance, but compatible with long term storage and deployment requirements. Modular vehicle maintenance, testing, replacing, or changing parts, done while in both operational or dormant status, must not adversely impact the system. Flight controls are to be highly automated to continually implement collision avoidance, terrain avoidance and attack maneuvering. The avionics suite of the mission management system should feature embedded intelligence to autonomously respond to dynamic, real-time events including pop-up threats and loss of datalink. A primitive survival mode would enable self-diagnosis and compensation for damage.[100] Finally, the airframe should be capable of generating three to four sorties each day with a surge capacity up to four or five sorties per day.[101] If, at the end of Phase II demonstrations, the UCAV performs as expected an acquisition phase could begin in FY05 with an Initial Operational Capability (IOC) before 2016.[102] With a bloodline running from early RPVs to modern UAVs and the technological advances in computers, UCAVs appear to have a promising future.

FUTURE

As with any evolutionary design one must learn to crawl before one can walk and run. The good news regarding UCAVs is that most of the crawling has already been done. In the next 10 years it should be possible to operate a totally autonomous UCAV. Dr Feigenbaum, a leading AI expert from Stanford University, believes that the USAF is currently "very far" from taking full advantage of AI systems. He perceives computers will be able to take over more of the tasks now performed by humans. Feigenbaum considers the military's most pressing need is for systems that can pull data from sensors and fuse it into current situational awareness. In *New World Vistas*, the USAF Scientific Advisory Board predicts overcoming these technological challenges by 2025.[103] General Fogelman framed it simply: "You've got to put a surrogate brain in that airplane."[104]

Toward this end programs are under development at Wright-Patterson AFB such as Automatic Target Recognition (ATR). ATR fuses radar, electrical, and optical sensors for prediction and recognition of unique target signatures. Through mathematical "fusion" of information from multiple sensors, the reliability of target and threat identification is increased. Research in multi-spectral and hyper-spectral sensors and for multi-function lasers and radars creates specialized sensors to detect and recognize concealed targets and environmental conditions.[105]

And the AI with the speed and complexity to use them, better than humans, will exist; possibly as early as 2015 according to Dr D. M. Bushnell of NASA's Langley Advanced Research Projects. Moore's Law postulates that technology capability doubles every 18 months while the cost remains the same. Bushnell maintains that affordable computing power rivaling that of the human brain will be available by 2015. Machines can then do the "random matching" operation that the human brain uses to "invent." Machines then become more creative as well as much faster than humans. Dr Bushnell declares, "Robotic warfare will CHANGE EVERYTHING, both what we build and how we fight it."[106]

Those who lead the fight will also change in significant ways. Future leaders will lack the experience of ever having operated in the environment they will control. Possibly the best example of this is the United States Space Command where "operators" man computer consoles. Again, General Fogelman may have envisioned this when he redefined the term "operator" from solely "aviators" to encompass a broader domain such as intelligence and space officers.

Wider, and wilder, prospects for the UCAV abound: long-range, hypersonic UCAVs allow a direct attack on high-value targets from US soil anywhere in the world in less than an hour,[107] better sensors enable UCAVs to autonomously capture the air-superiority role, and inexpensive naval air capability could be had through eliminating conventional aircraft carriers.[108] Finally there is no reason UCAV technology cannot be applied to other dangerous missions, both military and commercial such as aerial firefighting and low-level agricultural work.[109] AI technology will migrate to ground activities as well: tanks, self-propelled guns, and artillery seem logical choices.

RECOMMENDATIONS

Given the capabilities that may well explode from UCAV development, the US should take the following actions (given successful UCAV flight demonstrations):

- Procure UCAVs in numbers that account for attrition during takeoff and landing.
- Develop organizations for operations and maintenance personnel.
- Push for innovative maneuvers and tactics which exceed manned aircraft capabilities.
- Re-examine leadership.
- Be prepared to reduce overall JSF production.

CONCLUSIONS

Western governments cannot ignore their voters who seem unwilling to give up hopes of a "peace dividend" or to face the possibility of sacrificing a family member to what seems like an implausibly remote foreign threat. Additionally, the rising cost of modern major weapons systems is leading to what has been called structural disarmament. Taken together, these two factors militate towards the use of unmanned and less expensive systems which enable the nation to demonstrate that it can effectively meet armed conflicts. Improved survivability has been a top US technological priority for decades. The Pentagon has promoted standoff weapons, putting as much distance between American aviators and dense defenses as possible. The trend is certain to continue.

6,000 Words.

ENDNOTES

[1] Tamar A. Mehuron, "USAF Almanac 1999: The Air Force in Facts and Figures; Equipment," Air Force Magazine 82, no.5 (May 1999): 63. The USAF shows a total of 1838 A-10/OA-10s and F-16s in the Total Aircraft Inventory (TAI) with 1528 of those being in the Primary Aircraft Inventory (PAI). F-16s make up a great proportion 1210 PAI / 1470 TAI while A-10s and OA-10s account for 318 PAI / 368 TAI. This includes active duty, Guard and Reserve aircraft. TAI includes PAI as well as backup and attrition aircraft. Backup aircraft are assigned to a wing but without aircrews, yet must be maintained and flown. Attrition aircraft are assigned to a wing but without air or maintenance crews.

[2] John A. Tirpak, "Scoping Out the New Strike Fighter," Air Force Magazine 81, no. 10 (October 1998): 37.

[3] General Dugan observes that pre-WWII fighter aircraft had a half life of two years, fighters of the 1950s - five years; by the 1960s fighter airframes and technology lasted 10 years while fighters built in the 1970s lasted about 20 years. He cites tougher materials, better structures, improved design and the importance of flexible modern software for allowing avionics growth as general reasons for increased longevity. See Michael J. Dugan, "Operational Experience and Future Applications of Air Power," RUSI Journal 137, no. 4 (August 1992): 38.

[4] The single engine F-16, bought in large numbers during the 1980s and 1990s, will begin to wear out in 2005. Tirpak, "Scoping Out the New Strike Fighter," 36.

[5] Ian G. S. Curtis, "Remotely Piloted Vehicles: Only Shore of Imagination and Money," Defense and Foreign Affairs Strategic Policy 24, no. 9 (30 September 1996): 8.

[6] By this definition, systems such as the German TAIFUN and Israeli HARPY are cruise missiles, or more generically Unmanned Aerial Vehicles (UAVs); although they are often reported by the media as being the first UCAVs. TAIFUN is a piston engine powered flying bomb capable of cruising at 81 knots for up to four hours. It is guided to target by inertial navigation system (INS), Global Positioning System (GPS), terrain contour matching and has an autonomous millimetric wave radar system for terminal guidance. See Peter Lewis Young, "Unmanned Aerial Vehicles," Asian Defence Journal 11 (November 1997): 31. The Israel Aircraft Industries (IAI) Harpy is an anti-radar attack cruise missile discussed in Damian Kemp's article "Combat Drones Fly for Casualty Free War," Jane's Defence Weekly 31, no. 23 (9 June 1999): 88.

[7] UCAVs are alternatively known as Unmanned Tactical Aircraft (UTA). See Nick Cook, "Leaving the Pilot on the Ground," Jane's Defence Weekly 26, no. 1 (3 July 1996): 34.

[8] James Elliot, "UCAVs: Toward a Revolution in Air Warfare?" Military Technology 22, no. 8 (August 1998): 18.

[9] Ibid., 17-18.

[10] Prasun K. Sengupta, "Unmanned Aerial Vehicles: The Force Multiplier of the 1990's," Asian Defence Journal 12 (December 1998): 36.

[11] Lt Col David Eshel, "High Flying Surveillance: Israel Leads the World in Military Employment of Unmanned Aerial Vehicles," Armed Forces Journal International 135, no. 11 (June 1998): 30.

[12] Elliot, "UCAVs: Toward a Revolution in Air Warfare?" 15.

[13] Brian Walters, "RPVs—Yet to Fulfil Their Promise," Asian Defence Journal 12 (December 1995): 98.

[14] Curtis, "Remotely Piloted Vehicles," 8.

[15] John A. Tirpak, "The Robotic Air Force," Air Force Magazine 80, no. 9 (September 1997): 72.

[16] Elliot, "UCAVs: Toward a Revolution in Air Warfare?" 15.

[17] Curtis, "Remotely Piloted Vehicles," 8. Interestingly, in 1965 Israel also sought UAVs for reconnaissance and faced many of the same prejudices. The commander of the Israeli Air Force, Mordecai Hod, considered RPVs as an affront to the prestige of the fighter pilot. However, after losing several F-4s flying reconnaissance missions in 1970 the IAF policy changed. RPVs flew in the Yom Kippur War of 1973.

[18] Steve Shaker, "Saving Life, Limb—and Face—With Robotic Fighters," Defense and Diplomacy 9, no. 11-12 (October-November 1991): 55.

[19] Ibid., 56.

[20] Peter Lewis Young, "Will the RPV Replace All Combat Aircraft Types?" Asian Defence Journal 4 (April 1999): 38.

[21] Young, "Unmanned Aerial Vehicles," 30.

[22] Jean Dupont, "What Role for the Pilot in virtual Environment?" Interavia 52, no. 615 (December 1997): 42.

[23] Sengupta, 36.

[24] Malcolm R. Davis, "UCAVs and the Australian Defence Force in the Next Century," Asia Pacific Defence Reporter 25, no. 2 (February-March 1999): 24.

[25] Dr. David J. Musliner <musliner@htc.honeywell.com>, "UCAV Research," electronic mail message to Lt Col John Flade <john.flade@carlisle.army.mil>, 01 March 2000.

[26] Robert H. Williams, "Air Force Vision Anticipates Victory Via New Technology," National Defense 81, no. 526 (March 1997): 40.

[27] Tirpak, "The Robotic Air Force," 74.

[28] M. Thomas Davis, "Pilot-Less Craft Promise Combat Clout," National Defense 83, no. 548 (May/June 1999): 25.

[29] Davis, "UCAVs and the Australian Defence Force in the Next Century," 24.

[30] John A. Tirpak, "UCAVs Move Toward Feasibility," Air Force Magazine 82, no. 3 (March 1999): 32.

[31] Davis, "Pilot-Less Craft Promise Combat Clout," 25.

[32] David A. Brown and Maryann Lawlor, "Rivals Stretch Thinking to Tackle Next-Century Battlefield Demands," Signal 53, no. 3 (November 1998): 41.

[33] Young, "Will the RPV Replace All Combat Aircraft Types?" 38.

[34] Robert K. Ackerman, "Innovative Microelectronics Emerge From Federal Research," Signal 52, no. 8 (April 1998): 17.

[35] MicroSTAR is intended to carry out a variety of reconnaissance tasks which could include sampling the air for nuclear, biological, or chemical contamination. See John G. Roos, "Pocket Sized Stalker: Miniaturization Promises to Revolutionize Reconnaissance." Armed Forces Journal International 136, no. 3 (October 1998): 90.

[36] Col William D. Siuru, Jr., USMC, "Micro Flyers: Ultimate Unmanned Air Vehicles." Marine Corps Gazette 82, no. 1 (January 1998): 35.

[37] MIT's goal is a wingspan less than 15 cm with a speed up to 250 km/hr. Vanderbuilt University is researching UAV insects with a metal skeleton which allows them to change shape to enter small spaces or reduce its profile. Young, "Will the RPV Replace All Combat Aircraft Types?" 40.

[38] Ian G. S. Curtis, "UAVs Growing in Numbers Finally Become Militarily, Politically, and Industrially Attractive," Defense and Foreign Affairs Strategic Policy 22, no. 8 (31 August 1994): 12.

[39] Curtis, "Remotely Piloted Vehicles," 8.

[40] Stacey Evers, "Unmanned Fighters: Flight Without Limits," Jane's Defence Weekly 25, no. 15 (10 April 1996): 29.

[41] Cook, 34. Frank Capuccio, Lockheed Martin's JSF program manager, said robotic JSF is "theoretically feasible," given that the airplane's avionics architecture will accommodate such a conversion. Tirpak, "Scoping Out the New Strike Fighter," 40.

[42] Ibid., 35.

[43] Ibid., 34.

[44] Curtis, "Remotely Piloted Vehicles," 8.

[45] Williams, "Air Force Vision Anticipates Victory Via New Technology," 17.

[46] Young, "Unmanned Aerial Vehicles," 30.

[47] Cook, 35.

[48] Tirpak, "UCAVs Move Toward Feasibility," 34.

[49] Ibid., 34.

[50] Young, "Will the RPV Replace All Combat Aircraft Types?" 38.

[51] Davis, "Pilot-Less Craft Promise Combat Clout," 24.

[52] Evers, 28.

[53] Tirpak, "The Robotic Air Force," 71.

[54] Davis, "Pilot-Less Craft Promise Combat Clout," 25.

[55] Young, "Will the RPV Replace All Combat Aircraft Types?" 39.

[56] Cook, 34.

[57] Brown, 40-41.

[58] Robert H. Williams, "Unmanned Combat Aircraft Age is Rapidly Approaching," National Defense 82, no. 534 (January 1998): 22.

[59] Davis, "Pilot-Less Craft Promise Combat Clout," 24.

[60] Walters, 98.

[61] Young, "Will the RPV Replace All Combat Aircraft Types?" 39.

[62] Davis, "Pilot-Less Craft Promise Combat Clout," 24.

[63] Artur Knoth, "Aerial Weapons for a New Era," International Defense Review 26, no. 12 (December 1993): 962.

[64] Additionally, Congress authorized higher Aviator Continuation Pay rates. In 1998 the rates were upped from $12,000 to $22,000 per year. See Bruce D. Callander, "You and Your Year Group," Air Force Magazine 82, no. 3 (March 1999): 39-40.

[65] Brown, 41.

[66] Curtis, "UAVs Growing in Numbers," 12.

[67] Davis, "Pilot-Less Craft Promise Combat Clout," 25.

[68] Evers, "Unmanned Fighters: Flight Without Limits," 29.

[69] Tirpak, "UCAVs Move Toward Feasibility," 34.

[70] Evers, "Unmanned Fighters: Flight Without Limits," 29.

[71] Cook, 34.

[72] Davis, "Pilot-Less Craft Promise Combat Clout," 24.

[73] Young, "Will the RPV Replace All Combat Aircraft Types?" 38.

[74] Robert Wall, "Boeing Wins UCAV Contract," Aviation Week and Space Technology 150, no. 13 (29 March 1999): 85.

[75] James Elliot, "JSF for Everybody?" Military Technology 22, no. 3 (March 1998): 21.

[76] Digital strain gauges, such as those employed on the JSF design, can run along spars and other key components and tell the onboard diagnostics system how fatigued certain parts are and when they will need repair or replacement. This can save millions in maintenance previously done on a recommended schedule but which may or may not have been necessary. Tirpak, "Scoping Out the New Strike Fighter," 41.

[77] Tirpak, "UCAVs Move Toward Feasibility," 34.

[78] Others, like Canadair's CL-227 Flying Peanut, have been under development so long that doubt arises as to whether they will ever enter series production. See Walters, 96.

[79] Curtis, "Remotely Piloted Vehicles," 8.

[80] Ian G. S. Curtis, "The Unmanned Inevitability," Defense and Foreign Affairs Strategic Policy 26, no. 4-5 (April-May 1998): 14.

[81] Clarence A. Robinson, "Unmanned Aerial Vehicles Help Block, Evade Military Assaults," Signal 52, no. 8 (April 1998): 44.

[82] Curtis, "Remotely Piloted Vehicles," 8.

[83] Davis, "UCAVs and the Australian Defence Force in the Next Century," 26. Tirpak notes the JSF program explored removing many of the sensors (radar, infrared, target designation, etc) while beaming information in from satellites, Joint STARS, AWACS and other platforms, thereby saving weight and cost. That idea has been discarded. Recent versions call for the airplane to carry out its mission autonomously if downlinks are cut. See Tirpak, "Scoping Out the New Strike Fighter," 41.

[84] Curtis, "Remotely Piloted Vehicles," 8.

[85] Elliot, "UCAVs: Toward a Revolution in Air Warfare?" 18.

[86] Benjamin S. Lambeth, "Technology and Air War." Air Force Magazine 81, no. 10 (October 1998): 51.

[87] Elliot, "UCAVs: Toward a Revolution in Air Warfare?" 18.

[88] Peter Van Blyenburgh, "UAVs: Where Do We Stand?" Military Technology 23, no. 3 (March 1999): 29.

[89] Elliot, "UCAVs: Toward a Revolution in Air Warfare?" 18.

[90] "Unmanned Combat Air Vehicle System: Appendix A System Capability Document (SCD)," linked from Defense Advanced Research Projects Agency at "TTO-Programs - Unmanned Combat Air Vehicle (UCAV) System Capability Document," available from <http://www.darpa.mil/tto/programs/ ucav.html>; Internet; accessed 18 January 2000.

[91] Tirpak, "Scoping Out the New Strike Fighter," 40.

[92] Tirpak, "UCAVs Move Toward Feasibility," 35.

[93] "UCAV Operational Systems (UOS)," briefing slides, Langley Air Force Base, Air Combat Command, 21 July 1997.

[94] Tirpak, "The Robotic Air Force," 70.

[95] John G. Roos, "Expanding the Envelope: US Unmanned Aerial Vehicle Programs Now Range From Lightweight Reconnaissance to Heavyweight Attack Platforms," Armed Forces Journal International 135, no. 11 (June 1998): 26. The companies awarded Phase I UCAV demonstration systems contracts were: Lockheed Martin Tactical Aircraft Systems, Fort Worth, Texas; Northrop Grumman Corporation, Military Aircraft Systems Division, Pico Rivera, California; Raytheon Company, Raytheon Systems Company, Falls Church, Virginia, and the Boeing Company, Information, Space & Defense Systems, Phantom Works, Seattle, Washington. "Unmanned Combat Air Vehicle Advanced Technology Demonstration (UCAV ATD) Fact Sheet," Defense Advanced Research Projects Agency, July 1999.

[96] Wall, "Boeing Wins UCAV Contract," 84.

[97] Cook, 34.

[98] Musliner.

[99] Ibid., 85.

[100] The US Navy has considered a UCAV as a possible replacement for the F/A-18E/F under a program titled the Joint Semi-Autonomous Air Weapon System (JSAAWS). Robert Schwartz of the Naval Air Warfare Center at China Lake, California, explains that the Navy doesn't want an airframe where the pilot was merely taken out, nor does it want to weaponize an existing reconnaissance UAV; either of which is considered as simply a short term solution. The JSAAWS would be reusable with a life of about 1,000 flight hours and, ultimately, expendable. China Lake figures about 20 percent of the flights would be for training and maintenance. Three variants were considered with various capabilities. Individual airframe costs ranged from $10 to $40 million. Anticipated missions include SEAD, Close Air Support (CAS), anti-submarine warfare, and armed reconnaissance. The three variants are: 1) the low-end variant, pricing out at $10 million and capable of executing only air-to-ground missions such as CAS and SEAD, 2) the air arsenal ship, costing $25 million would have very long loiter, limited air-to-air and air-to-ground capabilities, 3) a high-end variant, with a price of $40 million would be capable of air-to-air and air-to-ground missions, would be highly intelligent and autonomous, carrying countermeasures and light, inexpensive weapons. Both the air arsenal ship, as well as the high-end variant, require extensive data links and long-range sensor suites. See Stacey Evers, "Air Arsenal Ship Leads Naval Study on UAVs," Jane's Defence Weekly 28, no. 5 (6 August 1997): 30.

[101] Brown, 39-40.

[102] Kemp, 90.

[103] The USAF currently uses about 100 AI systems, called expert systems, to perform mission planning. See Stacey Evers, "USAF: Developing a 30-Year Vision," Jane's Defence Weekly 25, no. 15 (10 April 1996): 27-28.

[104] Tirpak, "The Robotic Air Force," 74.

[105] Air Force Research Laboratory, "Automatic Target Recognition," undated; available from <http://www.sn.afrl.af.mil/Thrusts.htm>; Internet; accessed 18 February 2000.

[106] Dr D. M. Bushnell <d.m.bushnell@larc.nasa.gov>, "AI Impacts on Weapons Systems," electronic mail message to Lt Col John Flade <john.flade@carlisle.army.mil>, 23 December 1999. Dr Bushnell calls this "The age of the spiritual machines" which he feels will be a watershed in the human condition. "It will transcend warfare and force a complete re-examination and re-defination of the meaning of human life—caused by human replacement parts; doubling of life span; and machines which are smarter, more creative, stronger, better senses, and much longer lived than humans."

[107] Lambeth, 50.

[108] Davis, "UCAVs and the Australian Defence Force in the Next Century," 24.

[109] Brown, 41.

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